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TFSO LONG-PERIOD L-ARRAY NOISE COHERENCE

20 October 1967

Prepared For

AIR FORCE TECHNICAL APPLICATIONS CENTER
Washington, D. C.

By

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TELEDYNE, INC.

Under

Project VELA UNIFORM

Sponsored By

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Nuclear Test Detection Office
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TFSO LONG-PERIOD L-ARRAY

NOISE COHERENCE

SEISMIC DATA LABORATORY REPORT NO. 199

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AVAILABILITY

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ABSTRACT

Three long-period noise samples recorded at the TFSO L-array were analyzed for coherence properties. The results indicate that the ordinary coherence is generally high between elements 5-10 km apart and low between elements further apart. Multiple coherence is high for the first noise sample but low for the third sample.

Zero-delay noise summations for an additional sample produce about $N^{\frac{1}{2}}$ improvement over the average RMS noise level and beamforming of a large P-wave signal produces about $N^{\frac{1}{2}}$ improvement in signal-to-noise ratio.

INTRODUCTION

During the period from about 01 February 1967 to 06 April 1967, a six-element array of long period seismographs was operated in the vicinity of the Tonto Forest Seismological Observatory in Arizona. The L-shaped array was composed of two legs bearing ENE and SSE with lengths approximately 25 km and 15 km respectively (Figure 1). Each of the sites contained three-component Geotech Model 7505A vertical and 8700C horizontal seismometers (free periods of 20 sec); photo-cell amplifiers were at all sites except TFSO which has a standard photo-tube amplifier.

The purpose of the array was to record and analyze the spatial properties (coherence) of long-period noise in the vicinity of TFSO with a view towards installing a permanent long-period 40 km hexagonal array of seven elements.

ORDINARY COHERENCE

Noise samples from three different time periods were used for computing ordinary coherence. These samples, designated "Noise Sample #1" through "Noise Sample #3", are from the following time periods:

Noise Sample #1 - 25 February 67	0801Z
Noise Sample #2 - 26 March 1967	1025Z
Noise Sample #3 - 05 April 1967	1330Z

Noise Sample #1. This sample contains 4000 points digitized (by Geotech) at two points per second and prefiltered with a band-pass of 0.01 cps to 0.30 cps (half-power) with 18 db/octave rolloff. The ordinary coherences vs. frequency between all pairs of seismometers are shown in Figures 2 through 5. These coherences were obtained using a lag window of 50 points. As shown on these figures, the site PY-5 appears to have noise which is incoherent with the other sites. It is believed that there were no instrumental difficulties with this site (data are normal, visually, and the auto-spectrum agrees with the spectra from the other sites, as shown in

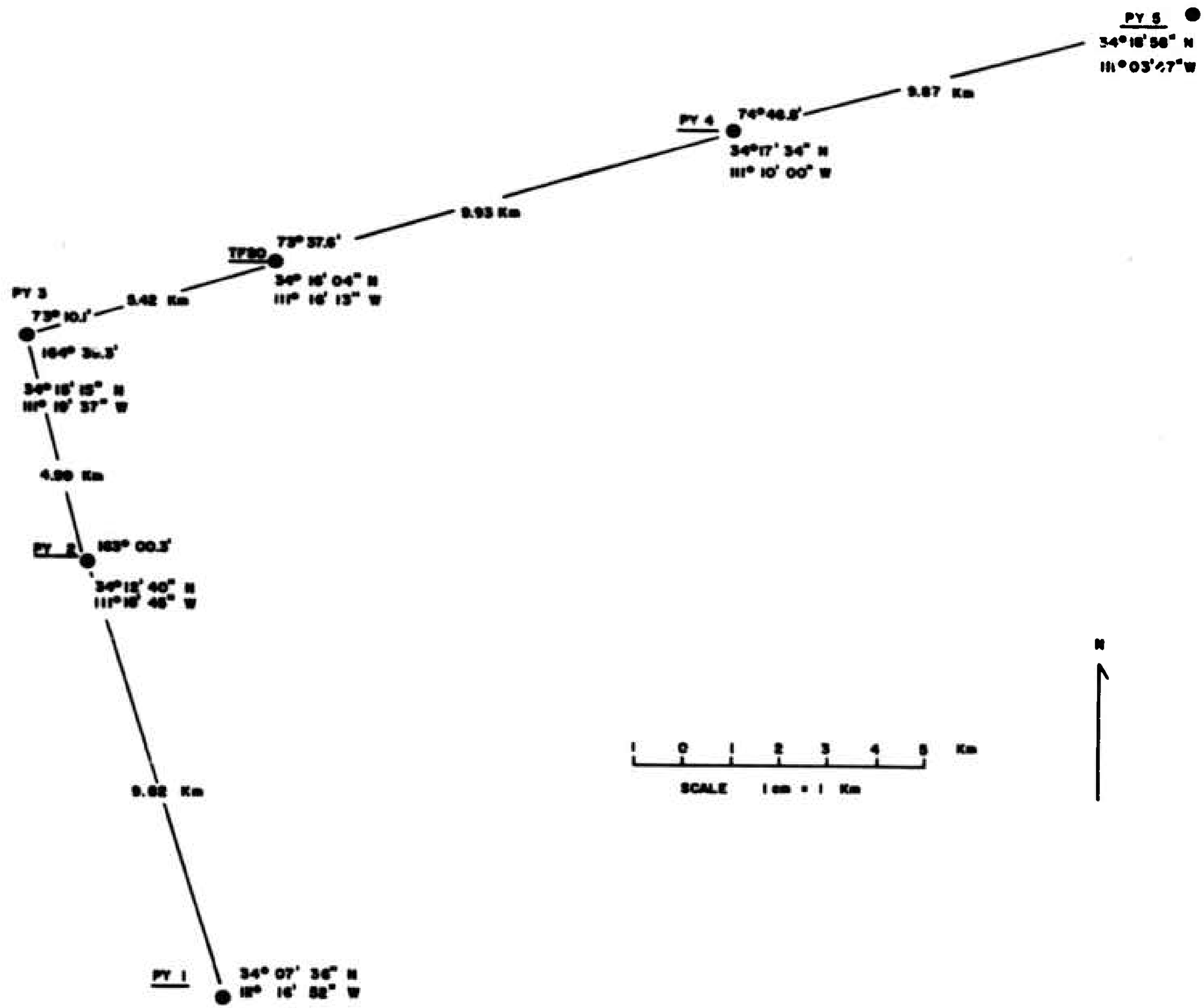


FIGURE 1. LOCATION MAP OF THE TFSO L-ARRAY.

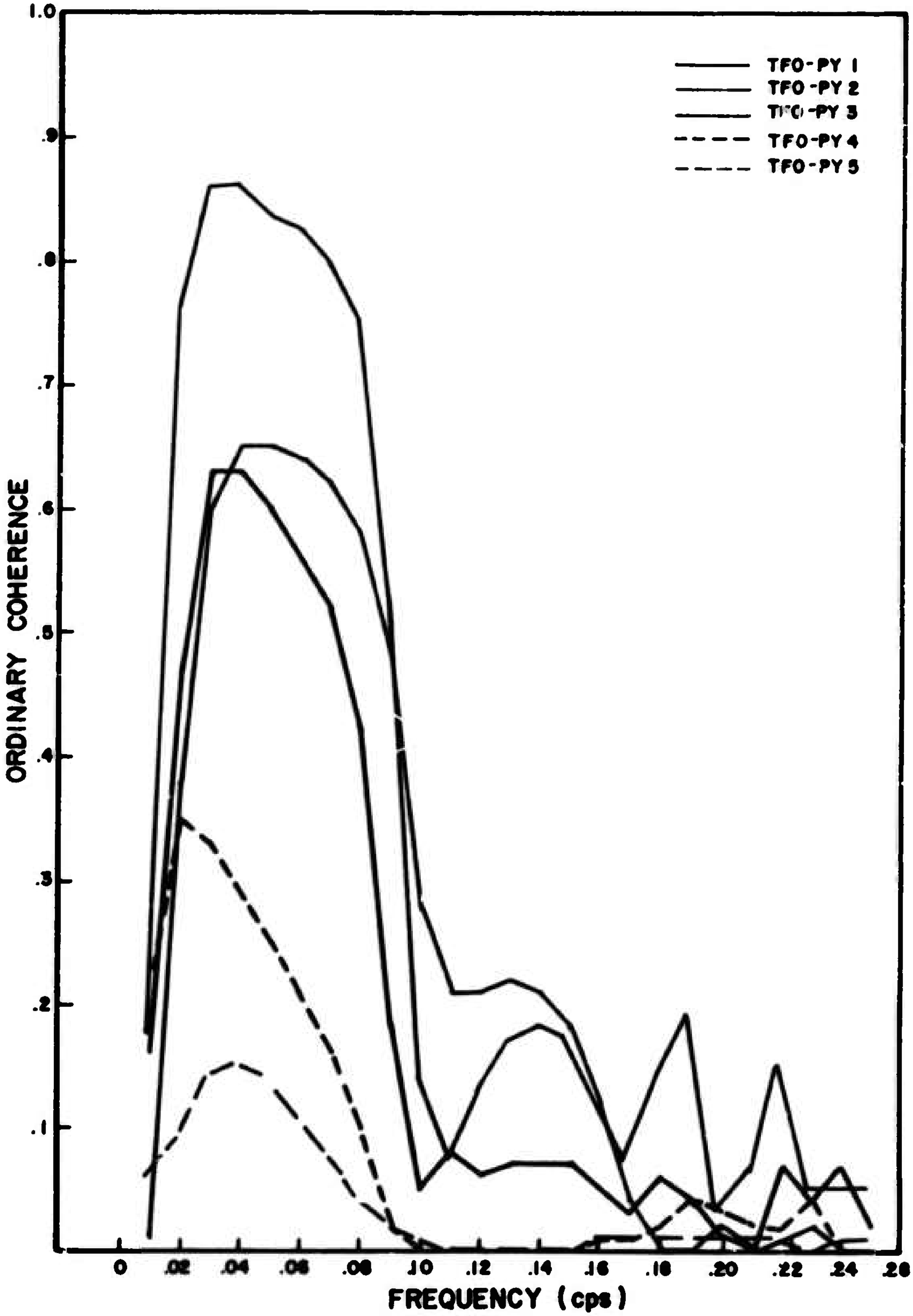


FIGURE 2. ORDINARY COHERENCE BETWEEN TFO AND PY1, PY2, PY3, PY4, PY5. NOISE SAMPLE #1.

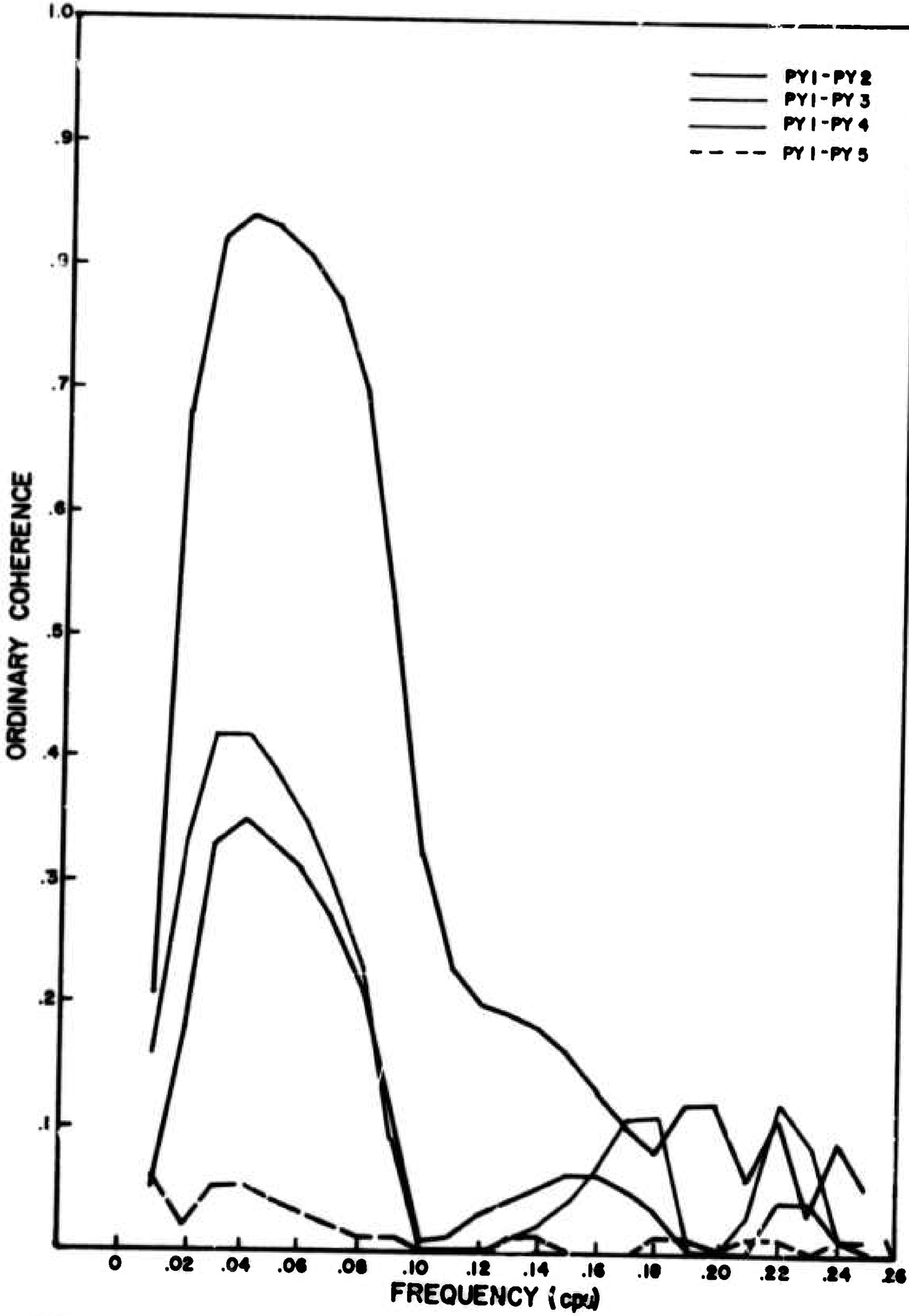


FIGURE 3. ORDINARY COHERENCE BETWEEN PY1 AND

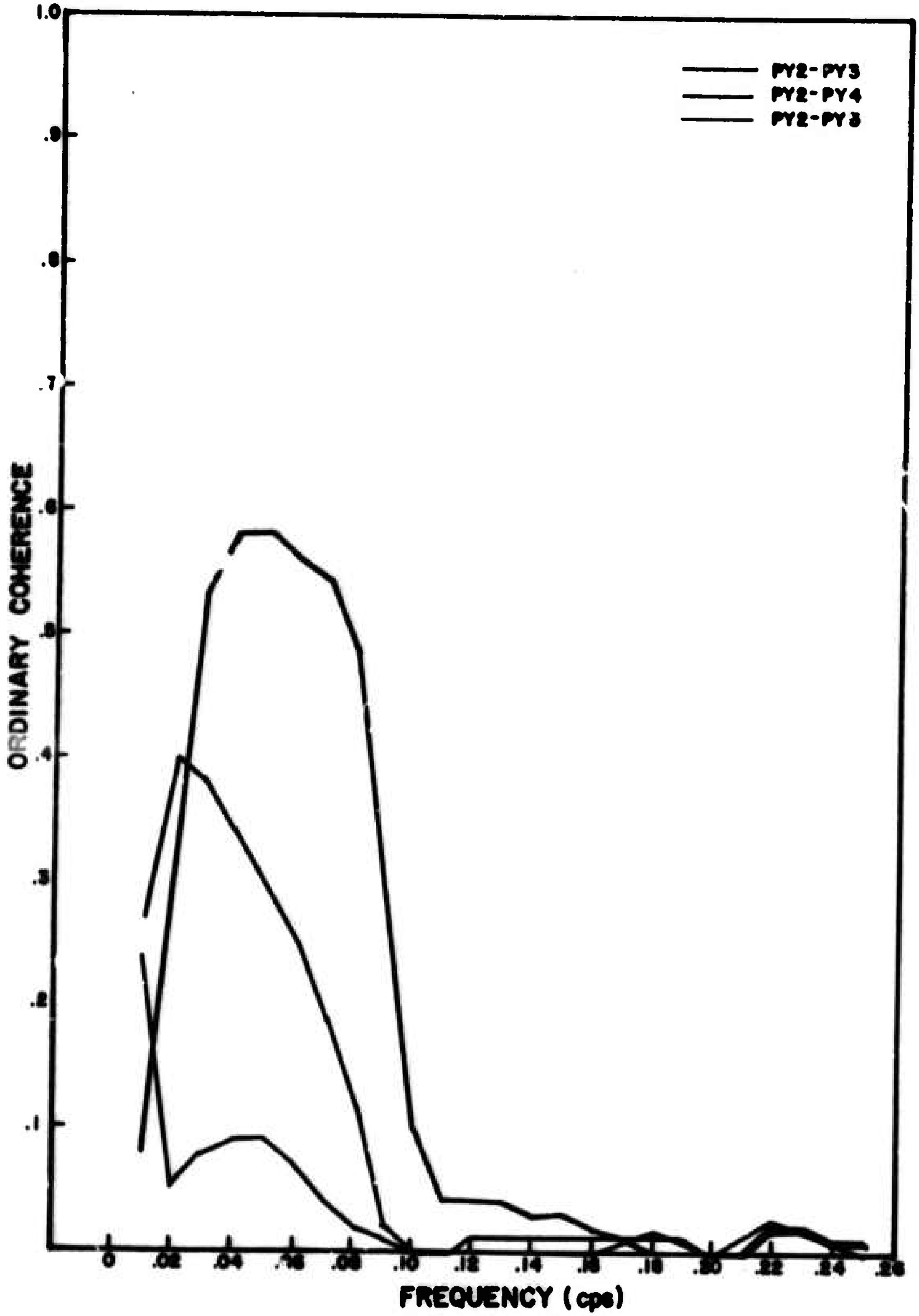


FIGURE 4. ORDINARY COHERENCE BETWEEN PY2 AND

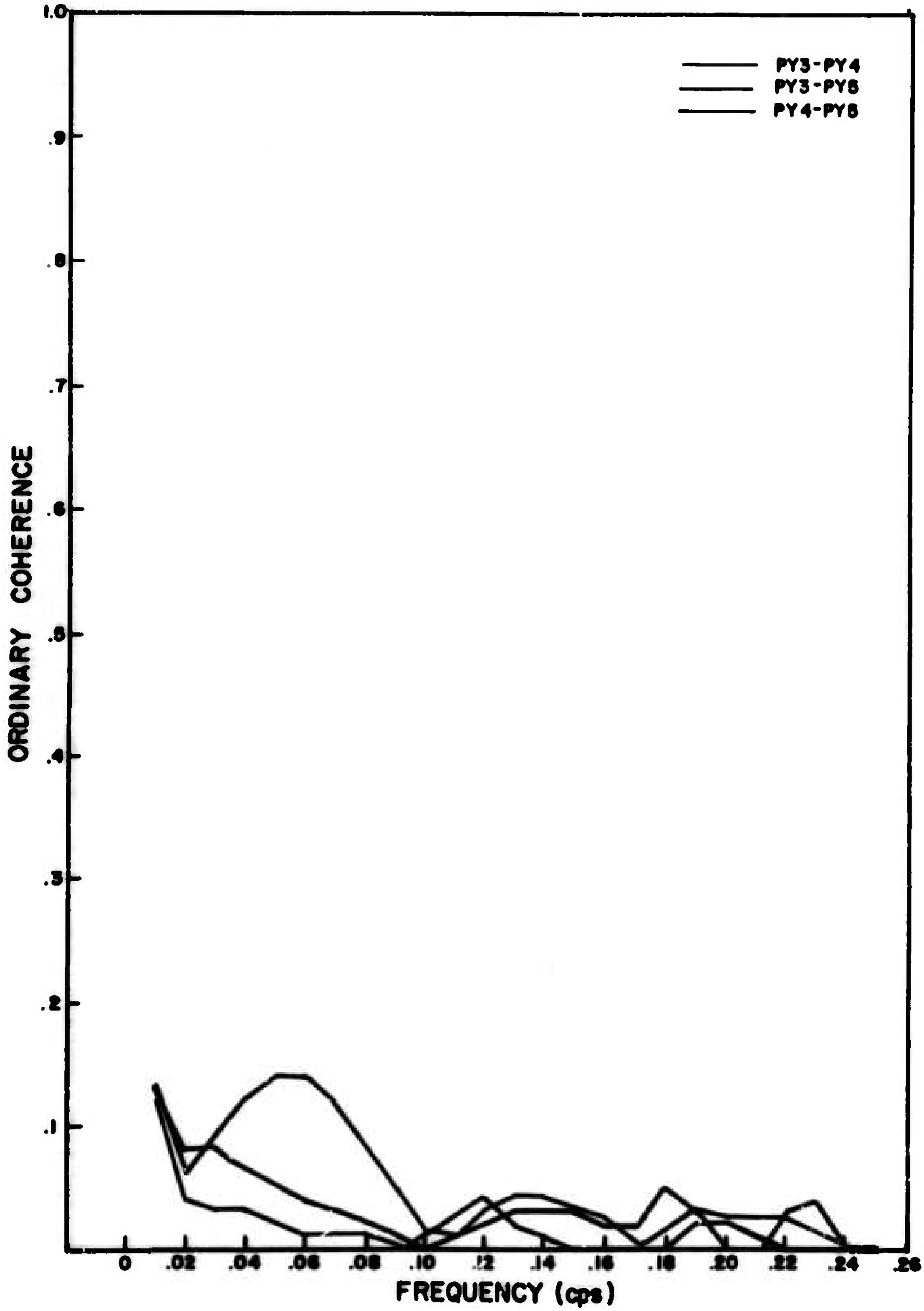


FIGURE 5. ORDINARY COHERENCE BETWEEN PY3 and PY4,
PY5 AND BETWEEN PY4 AND PY5, NOISE SAMPLE #1

Figure 6) so that the noise at this site is perhaps due to local winds, site emplacement properties, etc. Subsequent noise coherences from different times will be shown which indicate similar properties at PY-5 and to a lesser extent at PY-4 and PY-3.

Additional coherences were computed from the same data, but with lag windows of 200 points, for various (not all) pairs (Figures 7, 8, and 9) and of 400 points (Figure 10). There are no significant changes in the computed coherences using the longer lag lengths, except those anticipated, such as a general increase in coherence with the longer lag windows (see, for example, Chiburis and Dean, 1967a, b, c, d).

The characteristics of the bandpass filter applied to the data used for the results shown in Figures 2 through 10 (0.01 cps to 0.30 cps, 18 db/octave rolloff) were changed to 0.017 cps to 0.200 cps, 12 db/octave rolloff and coherences recomputed to note any effects due to filtering. Figures 11 through 14 show the coherence results of the tighter bandpass filter. The only significant differences occur at the higher frequencies, as expected, with more instability in computing the coherence.

Noise Sample #2. This sample contains 2910 points at one point per second (digitized at five points per second and decimated) prefiltered from 0.010 cps to 1.00 cps (24 db/octave) and then low-pass filtered with a high-cut of 0.50 cps. Ten-percent lags were used (290 points). The results for six pairs are shown in Figures 15 through 17. The noise between the array sites for this particular sample appears highly incoherent, generally remaining below 0.50 at the lower frequencies. This result suggests that a simple array summation should suppress the noise by a factor of $N^{\frac{1}{2}}$. A computer program, LOPSAN, is available at SDL (R. A. Hartenberger, personal communication) that measures the RMS noise level (and signal levels as well) of array data before and after summing, or beamforming. Root-mean-square noise measurements from data recorded on 12 February 1967 at 0730Z, 0750Z, and 0810Z were made to determine the amount of

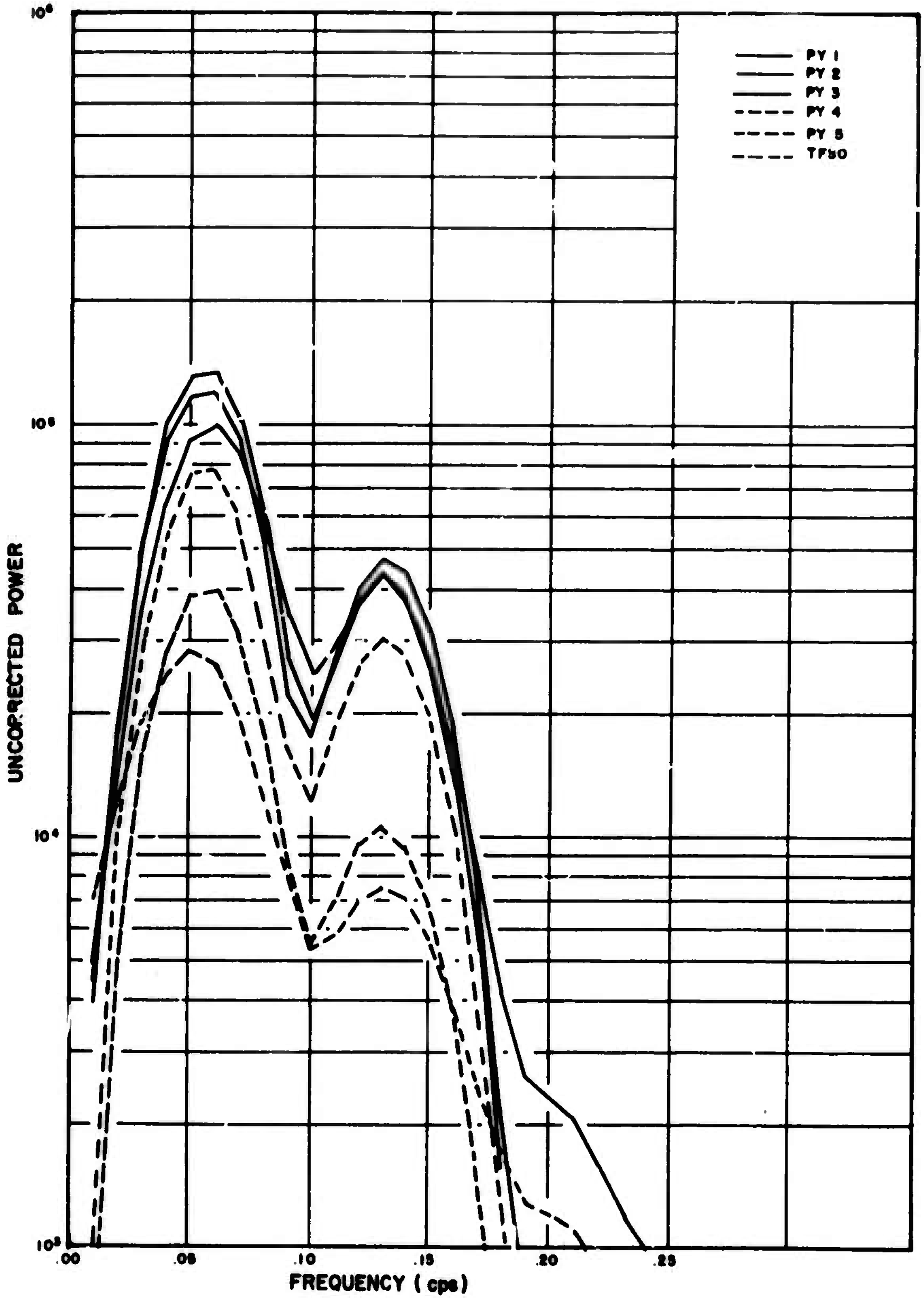


FIGURE 6. POWER SPECTRA AT THE TFSO L-ARRAY FOR NOISE SAMPLE #1.

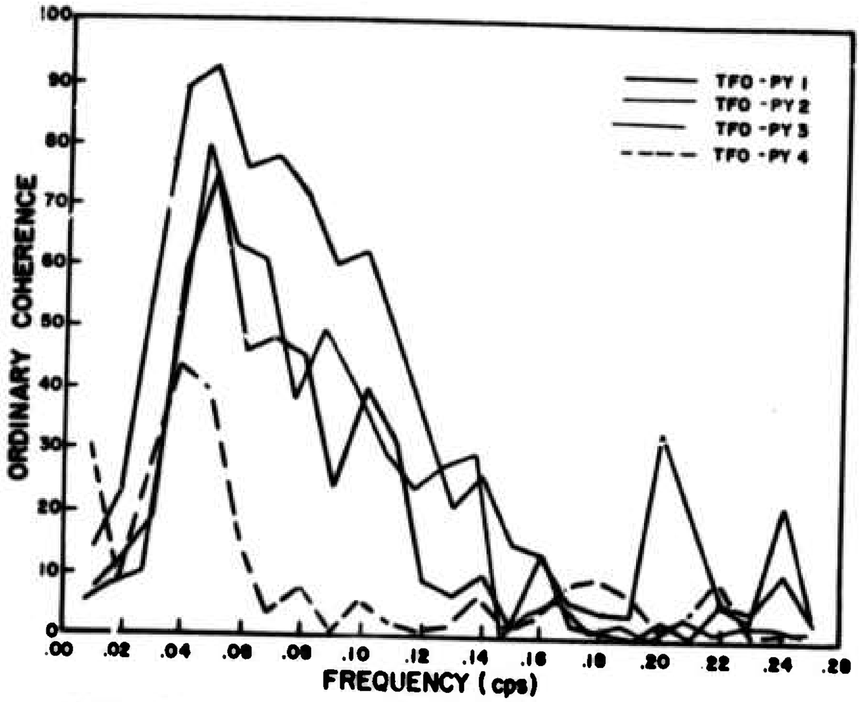


FIGURE 7. ORDINARY COHERENCE BETWEEN TFO AND PY1, PY2, PY3, PY4 FOR LAG WINDOWS OF 200 POINTS. NOISE SAMPLE #1.

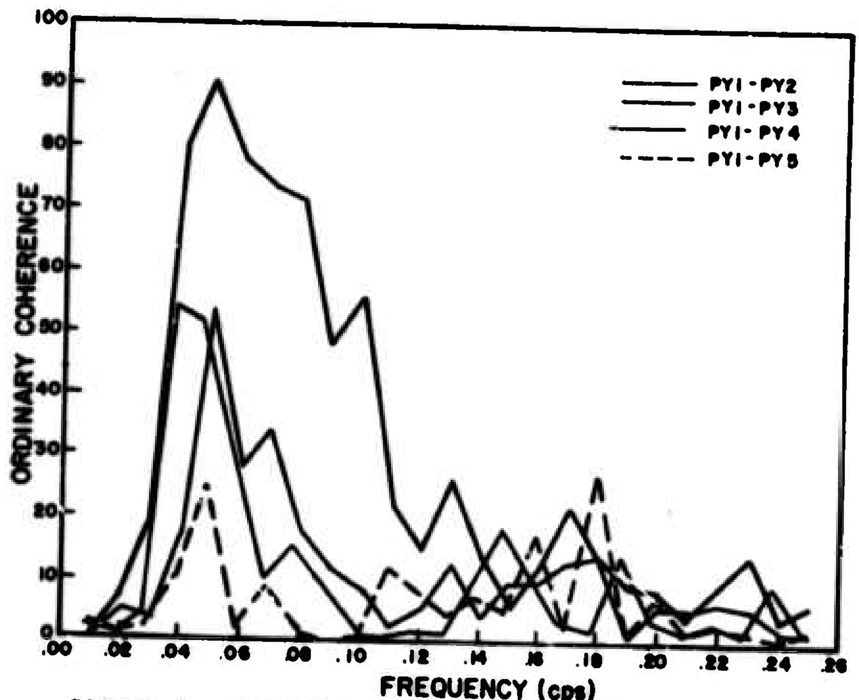


FIGURE 8. ORDINARY COHERENCE BETWEEN PY1 AND PY2, PY3, PY4, PY5 FOR LAG WINDOWS OF 200 POINTS. NOISE SAMPLE #1.

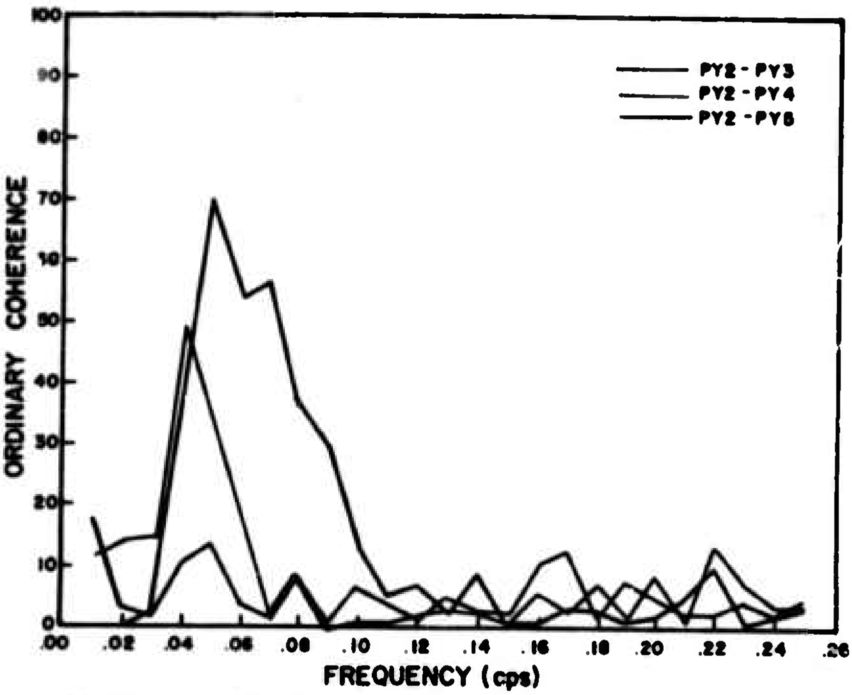


FIGURE 9. ORDINARY COHERENCE BETWEEN PY2 AND PY3, PY4, PY5 FOR LAG WINDOWS OF 200 POINTS. NOISE SAMPLE #1.

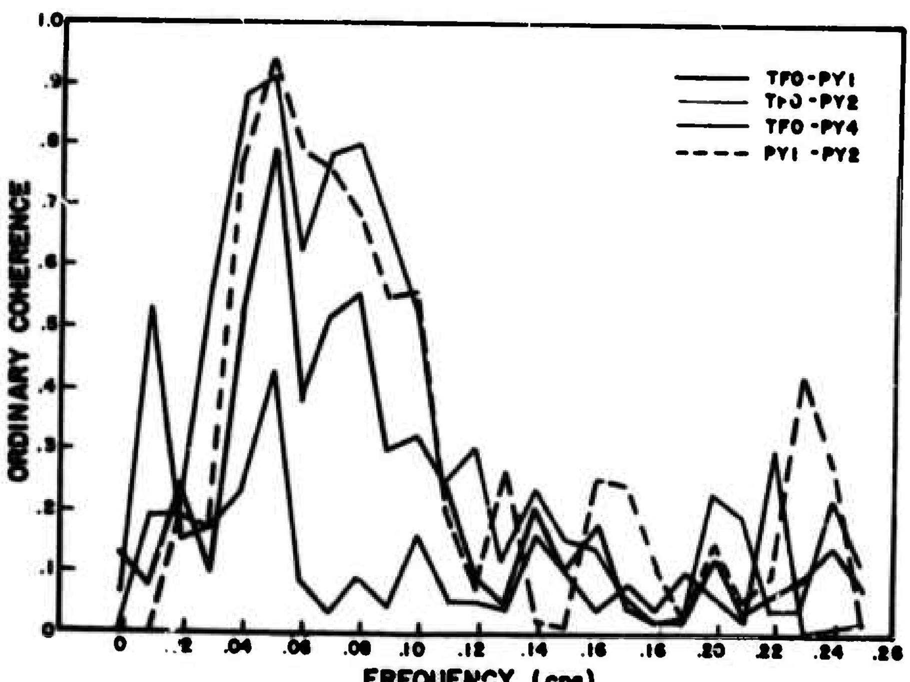


FIGURE 10. ORDINARY COHERENCE BETWEEN TFO AND PY1, PY2, PY4, AND BETWEEN PY1 and PY2 FOR LAG WINDOWS OF 400 POINTS. NOISE SAMPLE #1.

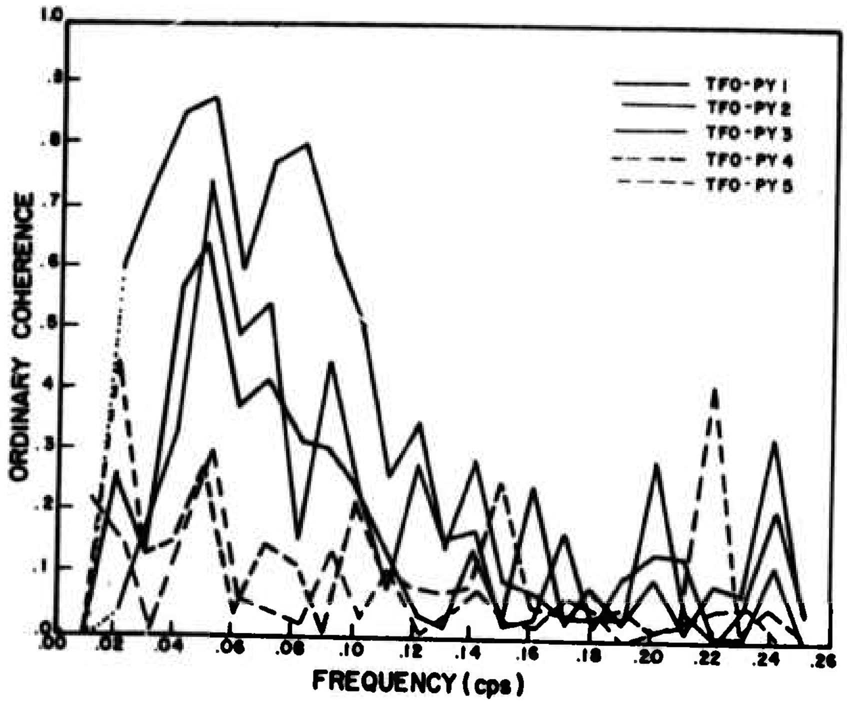


FIGURE 11. ORDINARY COHERENCE BETWEEN TFO AND PY1, PY2, PY3, PY4, PY5 WITH TIGHT FILTER. NOISE SAMPLE #1.

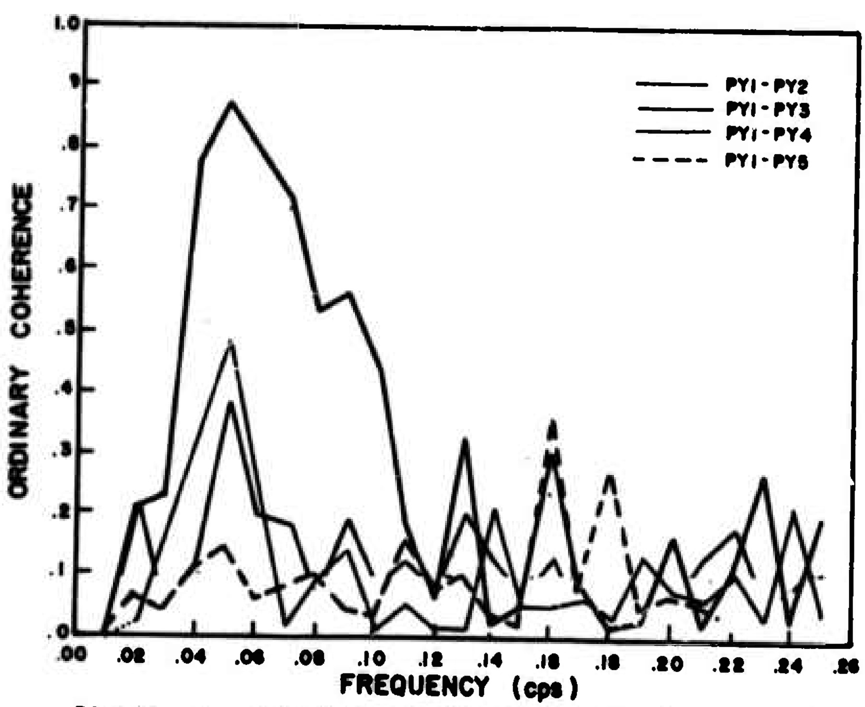


FIGURE 12. ORDINARY COHERENCE BETWEEN PY1 AND PY2, PY3, PY4, PY5 WITH TIGHT FILTER. NOISE SAMPLE #1.

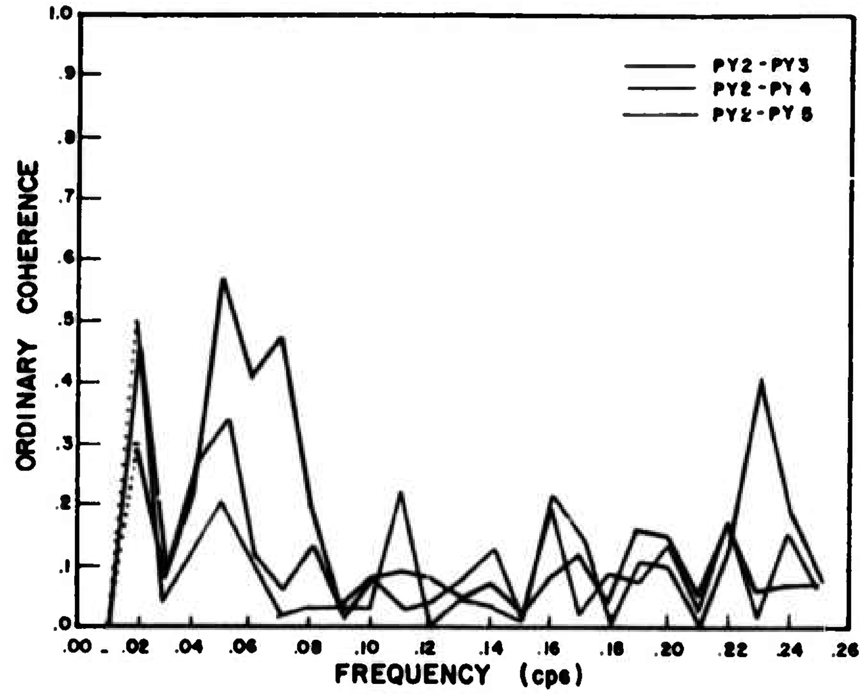


FIGURE 13. ORDINARY COHERENCE BETWEEN PY2 AND PY3, PY4, PY5 WITH TIGHT FILTER. NOISE SAMPLE #1.

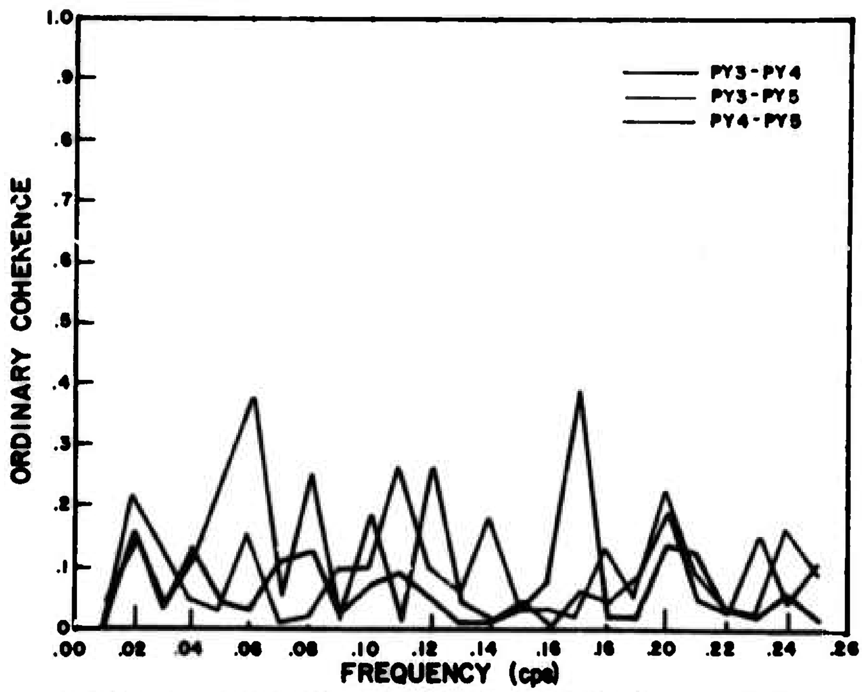


FIGURE 14. ORDINARY COHERENCE BETWEEN PY3, AND PY4, PY5, AND BETWEEN PY4 AND PY5 WITH TIGHT FILTER. NOISE SAMPLE #1.

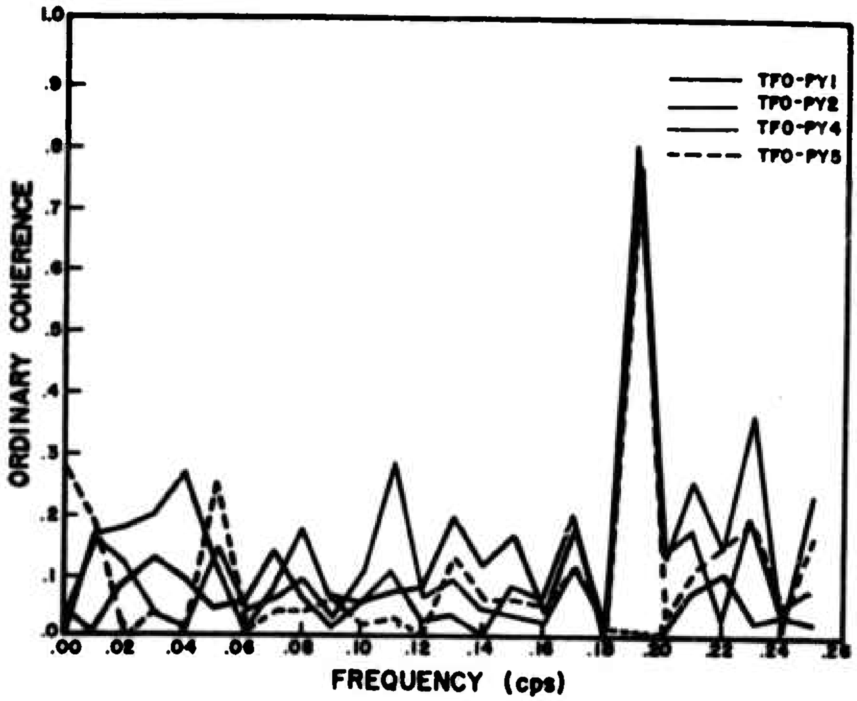


FIGURE 15. ORDINARY COHERENCE BETWEEN TFO AND PY1, PY2, PY4, PY5. NOISE SAMPLE #2.

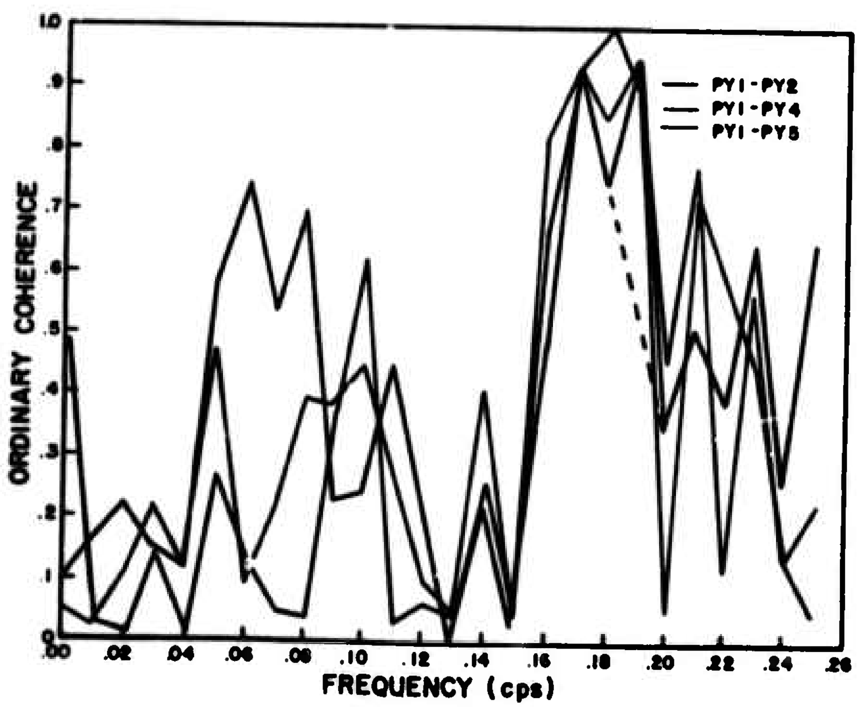


FIGURE 16. ORDINARY COHERENCE BETWEEN PY1 AND PY2, PY4, PY5. NOISE SAMPLE #2.

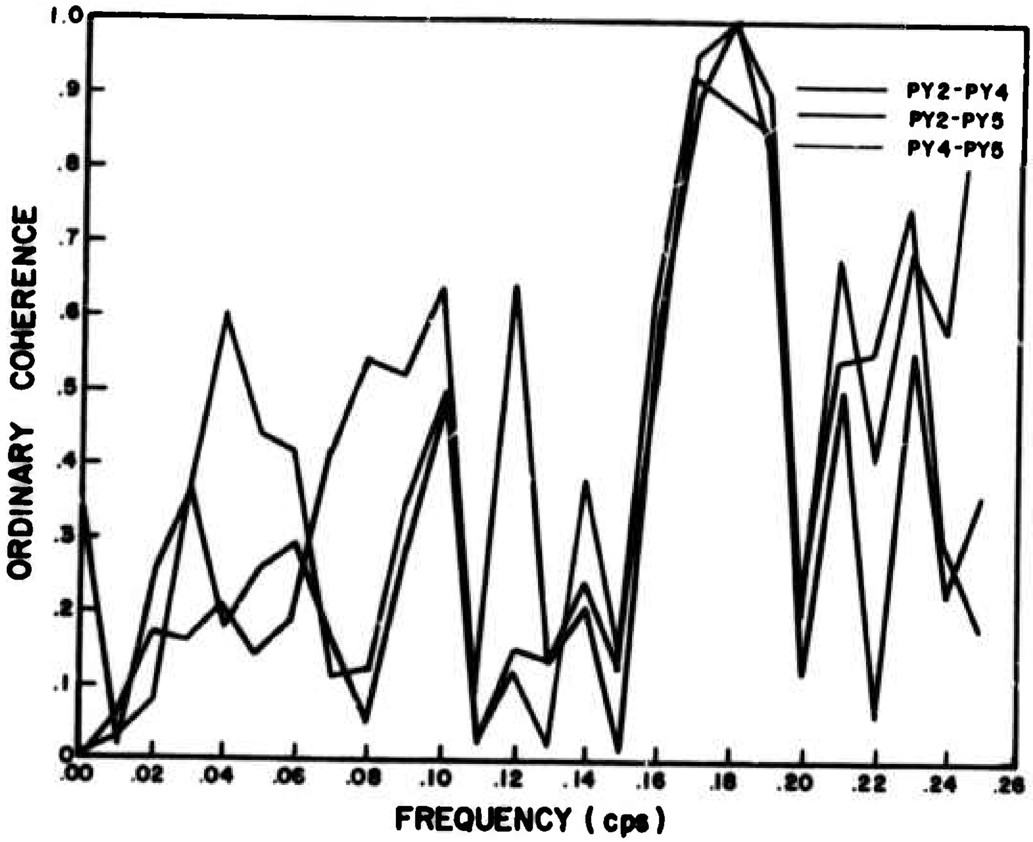


FIGURE 17. ORDINARY COHERENCE BETWEEN PY2 AND PY4, PY5, AND BETWEEN PY4 AND PY5. NOISE SAMPLE #2.

noise improvement possible with a zero-delay summation. This recording date was selected on the basis of high apparent noise background. Two combinations of array elements were used in the summations. The following table gives these results.

Time Sample	Elements	Avg.RMS*	Summation RMS	Improvement db	$N^{\frac{1}{2}}$db
0730-0750	TFO,PY1,2,3,4,5	47.66	21.01	7.1	7.8
0730-0750	TFO,PY1,2,4,5	46.98	22.02	6.6	7.0
0750-0810	TFO,PY1,2,3,4,5	47.82	18.84	8.1	7.8
0750-0810	TFO,PY1,2,4,5	47.01	21.89	6.6	7.0
0810-0830	TFO,PY1,2,3,4,5	58.93	25.13	7.4	7.8
0810-0830	TFO,PY1,2,4,5	57.97	26.24	6.9	7.0

*Each data trace was "demagnified" by an arbitrary value to yield about the same individual RMS level.

The data recorded at PY3 appeared to be questionable so array summations were made both with and without PY3 data. The improvement results in either case are close to the predicted $N^{\frac{1}{2}}$db indicating that the noise is spatially uncorrelated for zero-delay summations.

The spectra for Noise Sample #2 at five of the array sites is shown in Figure 18.

<u>Noise Sample #3</u>. This sample contains 3574 points (digitized at one point per second), band-passed from 0.017 cps to 0.500 cps (12 db/octave), and low-passed with a high-cut at 0.35 cps. Again, 10% lags (360 points) were used.

The results for all station pairs are shown in Figures 19 through 22.

MULTIPLE COHERENCE

Multiple coherences as a function of frequency were computed for Noise Samples #1 and #3. Multiple coherence indicates the number of input data channels which would be necessary to describe a noise field and gives a quantitative measure, versus frequency, of how well a linear combination of these n imput channels can match the (n + 1)st channel. The selected output channel for both noise samples was TFO and the inputs were PY1 through PY5. These results, shown in Figure 23, indicate

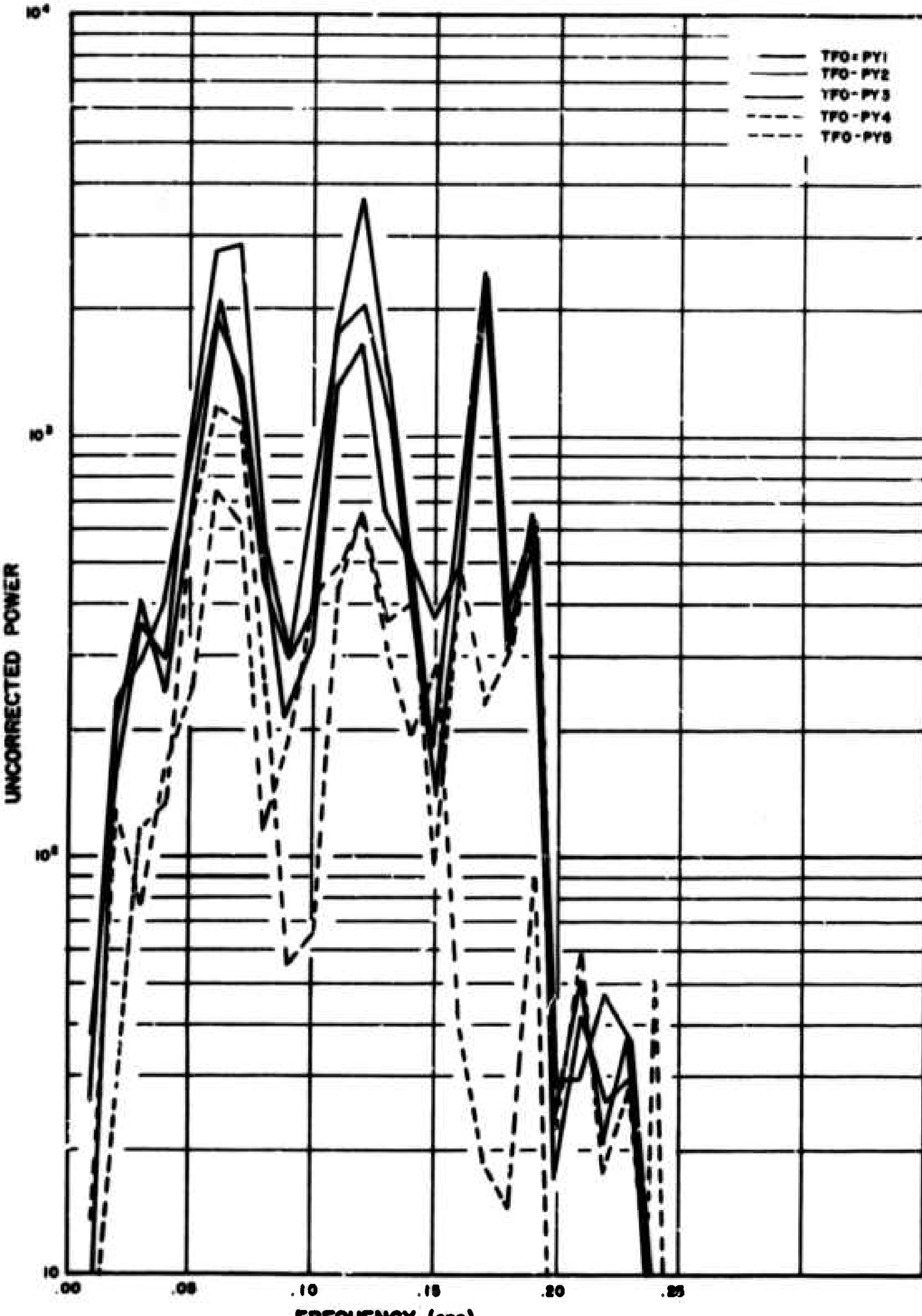


FIGURE 18. POWER SPECTRA AT THE TFSO L-ARRAY FOR NOISE SAMPLE #2.

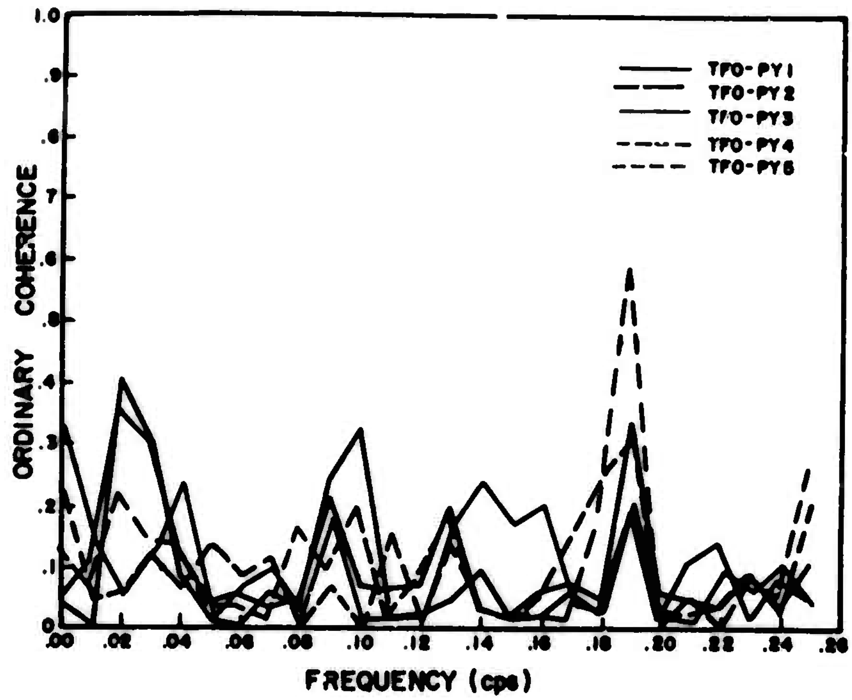


FIGURE 19. ORDINARY COHERENCE BETWEEN TFO AND PY1, PY2, PY3, PY4. NOISE SAMPLE #3.

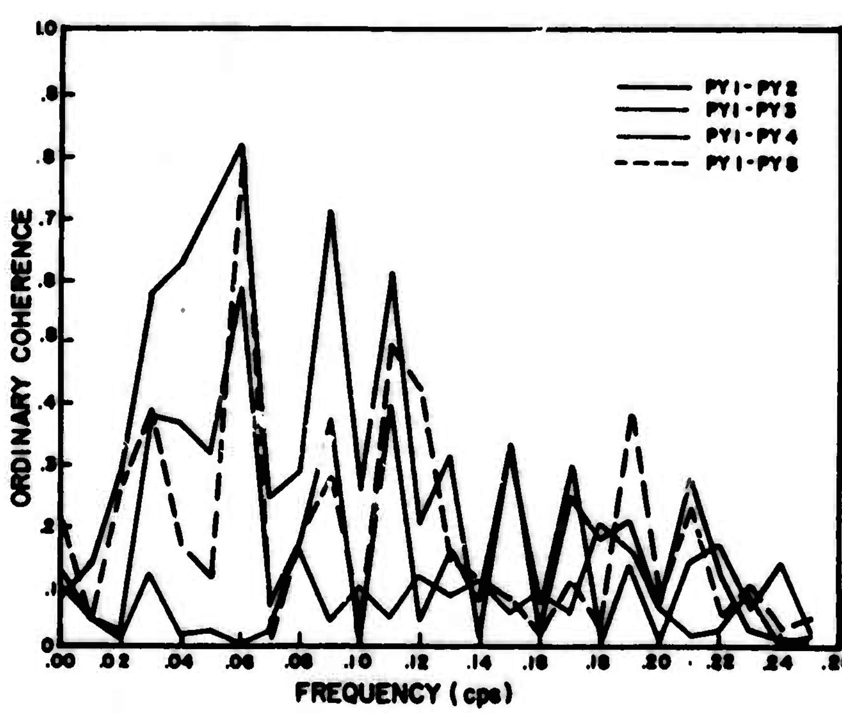


FIGURE 20. ORDINARY COHERENCE BETWEEN PY1 AND PY2, PY3, PY4, PY5. NOISE SAMPLE #3.

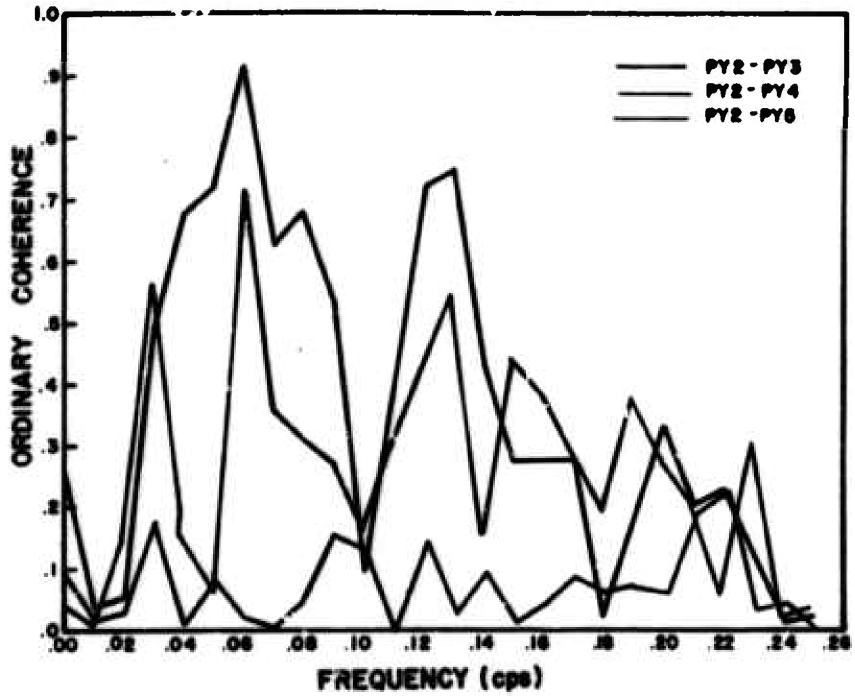


FIGURE 21. ORDINARY COHERENCE BETWEEN PY2 AND PY3, PY4, PY5. NOISE SAMPLE #3.

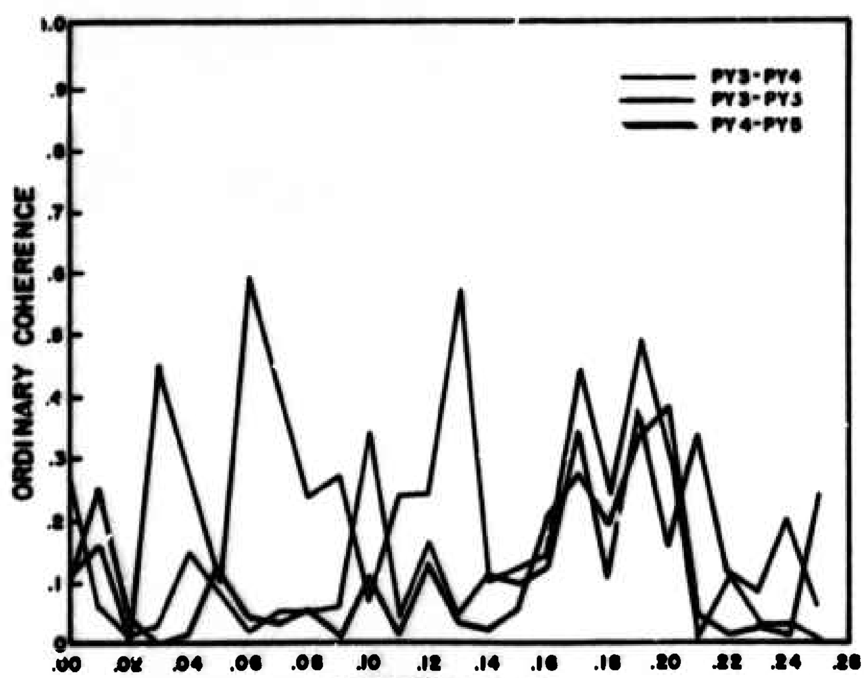
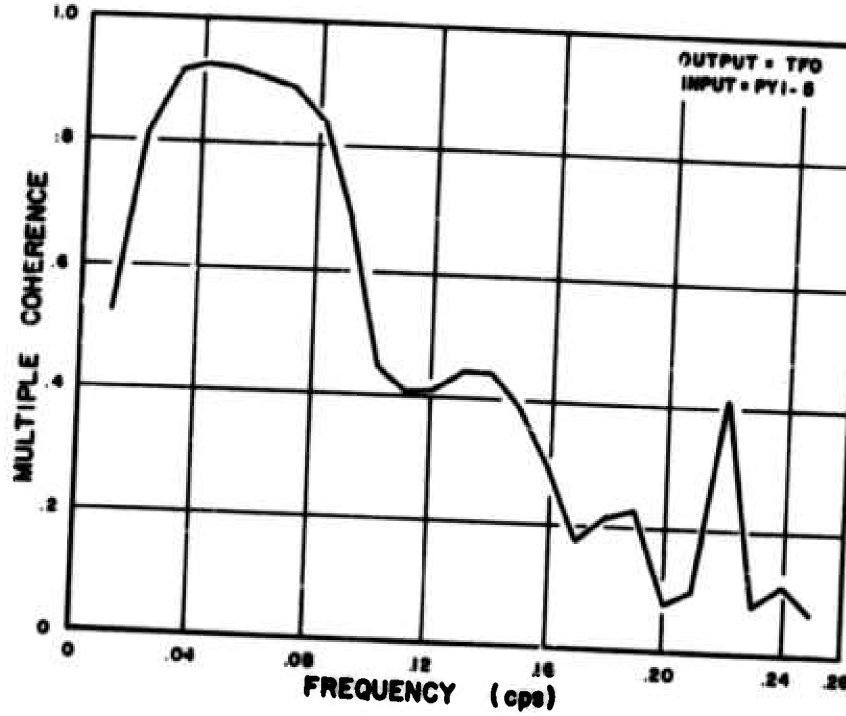


FIGURE 22. ORDINARY COHERENCE BETWEEN PY3, AND PY4, PY5 AND BETWEEN PY4 AND PY5. NOISE SAMPLE #3.



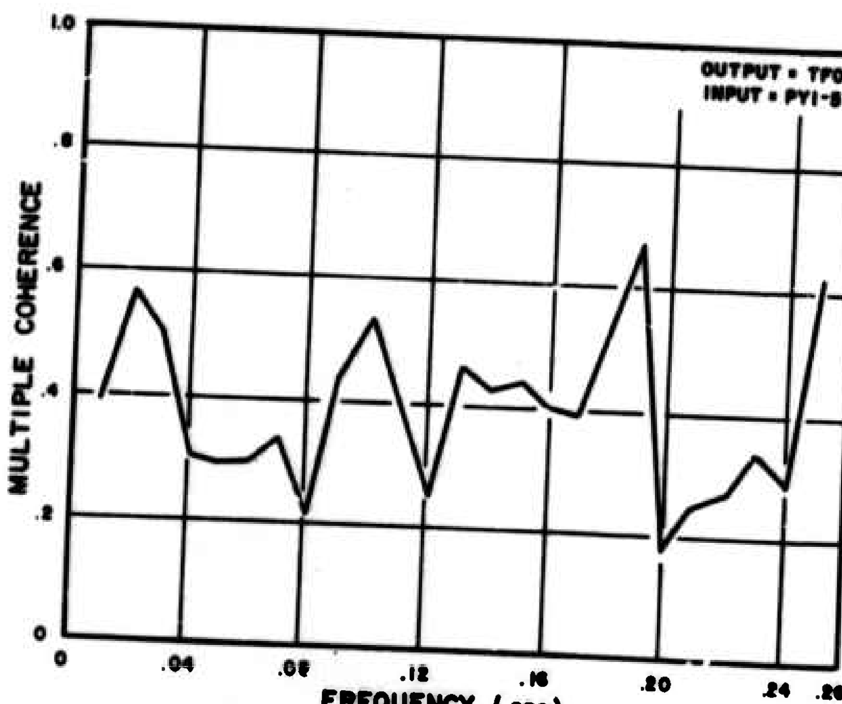


FIGURE 23. MULTIPLE COHERENCE WITH TFO AS OUTPUT AND PY1 THROUGH PY5 AS INPUTS. NOISE SAMPLE #1 (UPPER) AND NOISE SAMPLE #3 (LOWER).

that noise sample #3 is multiply incoherent (less than about 0.6) at all frequencies, whereas noise sample #1 is highly coherent at frequencies between 0.02 cps and 0.09 cps. The low multiple coherence for sample #3 shows that there are no (or few) linear filter relations between the six elements in the array.

RECORDED SIGNALS

Figure 24 shows a strong Love wave recorded by the horizontal instruments at the six sites in the array. Visually, each site appears to record very closely the same signal data on all instruments.

A large teleseismic event was recorded on 13 February 1967 at about 2300Z. Program LOPSAN was used to determine the P-wave S/N improvement from beamforming. Time delays were determined by eye. The results are given below.

Element	S/N
PY1	10.70
PY2	19.90
PY4	19.21
PY5	26.79
TFO	20.50
Mean	19.42
Phased sum	42.72
db improvement	6.8
$N^{1/2}$db	6.6

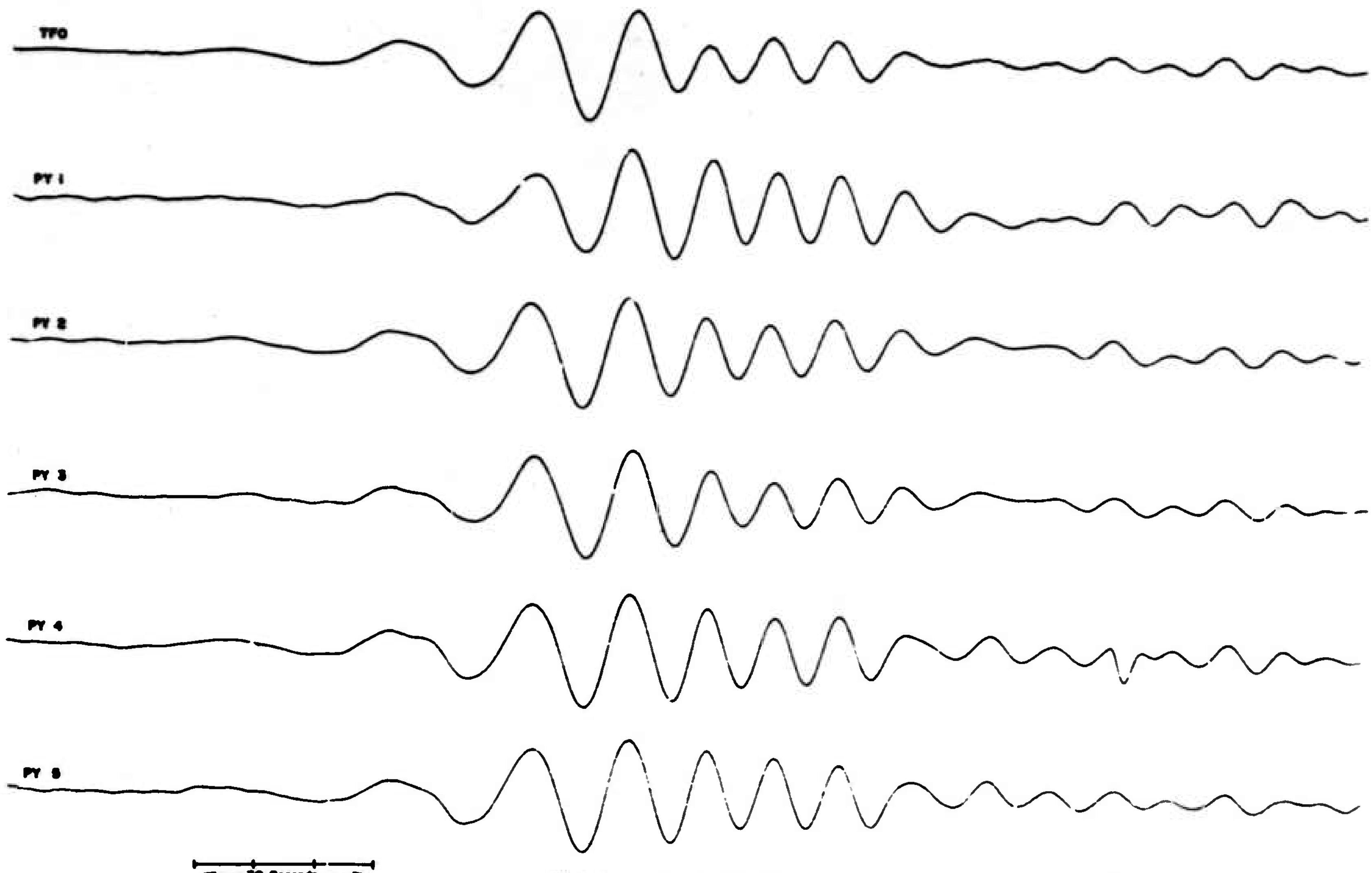


FIGURE 24. LARGE LOVE-WAVE SIGNALS RECORDED AT THE TFSO L-ARRAY.

CONCLUSIONS

1. Ordinary coherence within the passband is high (greater than 0.8) between elements 5-10 km apart, low (less than about 0.6) between elements further apart. Noise Sample #2, however, has low coherence between all sites at all frequencies.

2. The sites PY5 and PY4 are generally incoherent with the other sites, probably due to local noise characteristics.

3. Multiple coherence is high (greater than 0.7) between 0.02 cps and 0.09 cps for Noise Sample #1 but low (less than 0.6) at all frequencies for Noise Sample #3.

4. Zero-delay RMS noise summations produce about $N^{\frac{1}{2}}$ improvement over the average RMS noise level.

5. Beamforming produces about $N^{\frac{1}{2}}$ improvement in signal-to-noise ratio.

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Chiburis, E. F. and W. C. Dean, 1967a, "Multiple Coherence of Long Period Noise at LASA", Report No. 189, Seismic Data Laboratory, Teledyne, Inc., Alexandria, Virginia.

____________ 1967b, "Multiple Coherence of Short Period Noise at LASA", Report No. 190, Seismic Data Laboratory, Teledyne, Inc., Alexandria, Virginia.

____________ 1967c, "Multiple Coherence at 3 Vertical Arrays, UBSO, GV-TX, AP-OK", Report No. 191, Seismic Data Laboratory, Teledyne, Inc., Alexandria, Virginia.

____________ 1967d, "Multiple Coherence of Short Period Noise at UBSO and TFSO", Report No. 192, Seismic Data Laboratory, Teledyne, Inc., Alexandria, Virginia.

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13. ABSTRACT

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Zero-delay noise summations for an additional sample produce about $N^{\frac{1}{2}}$ improvement over the average RMS noise level and beamforming of a large P-wave signal produces about $N^{\frac{1}{2}}$ improvement in signal-to-noise ratio.

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